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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

ORIGINALLY ISSUED
February 1946 as
Restricted Bulletin L5K29

AN ANALYSIS OF THE FATIGUE LIFE OF AN AIRPLANE WING STRUCTURE UNDER OVERLOAD CONDITIONS

By Abbott A. Putnam and Thomas D. Reisert

Langley Memorial Aeronautical Laboratory
Langley Field, Va.

NACA

WASHINGTON

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NACA RB No. L5K29 [redacted]

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RESTRICTED BULLETIN

AN ANALYSIS OF THE FATIGUE LIFE OF AN AIRPLANE WING STRUCTURE UNDER OVERLOAD CONDITIONS

By Abbott A. Putnam and Thomas D. Reisert

SUMMARY

Results of an analysis to determine the effect of overload operations on wing fatigue life are presented. The investigation was confined to one transport-type airplane, which was assumed to operate at cruising power and with overload up to 50 percent of design gross weight.

Overload weight concentrated in the fuselage was found to adversely affect the fatigue life, but overload weight distributed proportionally to the design gross weight had negligible effect on the fatigue life. The fatigue life, furthermore, was adversely affected by overload to a smaller degree than the single-gust life. As in the case of single-gust life, the wing-weight ratio was a main factor in determining the relative reduction of fatigue life by overload.

INTRODUCTION

Fatigue life expectancy in normal transport operations was investigated in reference 1 and was found to be of equal importance with the single-gust life. The effect of overload operation of transport airplanes on the probability of encountering single critical gusts was investigated in reference 2 and the frequency of critical gusts was found to increase rapidly with overload. The effect of overload operation on fatigue strength, however, has not heretofore been evaluated, hence the investigations of references 1 and 2 are combined herein to permit such evaluation and to determine the relative importance of fatigue and single-gust failures under conditions of overload operation. The

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method of evaluation has been fully described in references 1 and 2 and will not be further mentioned.

CONDITIONS OF ANALYSIS

The analysis is based on an airplane possessing the size and aerodynamic configuration of the Douglas DC-3, the pertinent characteristics of which are given in reference 1. The assumptions are made that the airplane is operated at cruising power at all overloads and in all atmospheric conditions, that the wing structure is of 17S-T aluminum alloy, and that the yield stress of the material of which the wing is made will just be attained at the design gust-load factor. A stress-concentration factor of 2.4 is generally used, although factors of 3.6 and 6.0 are also used in certain cases. The ratio of design wing weight to design gross weight (wing-weight ratio) is varied from 0 to 0.8 to show the effect of this parameter.

All varying stresses in the airplane wing structure are assumed to be induced solely by atmospheric gusts, the frequency distribution of which parallels the frequency distribution of reference 1. As pointed out therein, the random sequence in which the larger gusts are encountered requires the definition of a maximum and of a minimum fatigue life.

Two limiting conditions of overload distribution are investigated herein. In the first condition (case I) the weight distribution of the overloaded airplane is the same as for the condition of design gross weight; hence, for any given load factor, the increase in bending moments and shears will be proportional to the increase of gross weight. In the second condition (case II) the overload is concentrated in the fuselage; hence, for any constant load factor, the bending moments and shears increase more rapidly than the increase in gross weight.

RESULTS AND DISCUSSION

The effect of overload on fatigue life is shown in figure 1. The maximum and minimum lives are given for stress-concentration factors of 2.4 and 6.0 and for the

two limiting cases of overload. The fatigue life falls off quite rapidly with increasing overload for case II, in which the overload is concentrated in the fuselage, but remains essentially constant for case I, in which the overload is proportionally distributed. In addition, the general trends of the maximum and minimum fatigue lives are the same with increasing overload, thus only the minimum fatigue life is further considered.

A study of figure 1 shows the usual reduction in fatigue life that may be expected with an increase in stress-concentration factor and also reveals a variation of the effect of overload with stress-concentration factor. This variation is investigated for case II in figure 2, in which the ratio of the life at the overload condition to the life at the design-load condition is plotted for stress-concentration factors of 2.4, 3.6, and 6.0. The reduction of the unfavorable effect of overload on fatigue life with increase in stress-concentration factor is quite marked.

Since in figure 2 the ordinate is a ratio of lives, it is possible to put the frequency of occurrence of critical gusts (single-gust life) on an equivalent basis with fatigue life. It is apparent that the single-gust life is affected by overload to a much greater extent than the fatigue life. If an airplane were so designed that the fatigue life and single-gust life were of equal importance at design gross weight, the single-gust life apparently would become much more important at overload conditions than the fatigue life. Any fatigue damage, however, is a permanent damage, having an influence on the total fatigue life of the individual airplane; whereas no damage is inherent in the increased probability of occurrence of critical gusts at overload conditions unless a critical gust is encountered. In other words, when the overload is discontinued, the airplane is still potentially as good as any other airplane of its type with respect to single critical gusts, although the fatigue life has been reduced.

Figure 3 shows the effect of wing-weight ratio on the ratio of the fatigue life at overload to the fatigue life at design gross weight. It is evident that the higher the wing-weight ratio, the greater will be the effect of concentrated overload on fatigue life. The wing-weight ratio is thus a main factor in determining

the reduction in fatigue life for conditions of concentrated overload.

Since case I is equivalent to case II at a wing-weight ratio of zero, an estimate of the effect of an overload distribution intermediate to case I and case II may also be made from figure 3.

CONCLUSIONS

The effect of overload operation on the wing fatigue life of a representative transport-type airplane has been evaluated for various load distributions, amounts of overload, and stress-concentration factors. For the airplane used in the analysis and for operation at constant power, the following conclusions are indicated:

1. The fatigue life of the airplane wing was adversely affected by operation at overload when concentrated in the fuselage. When the overload was distributed proportionally to design gross weight, the fatigue life was not significantly affected.

2. For any distribution of overload, the single-gust life was more seriously affected than the fatigue life.

3. For conditions of concentrated overload, the wing-weight ratio was a main factor in determining the reduction in fatigue life.

Langley Memorial Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va.

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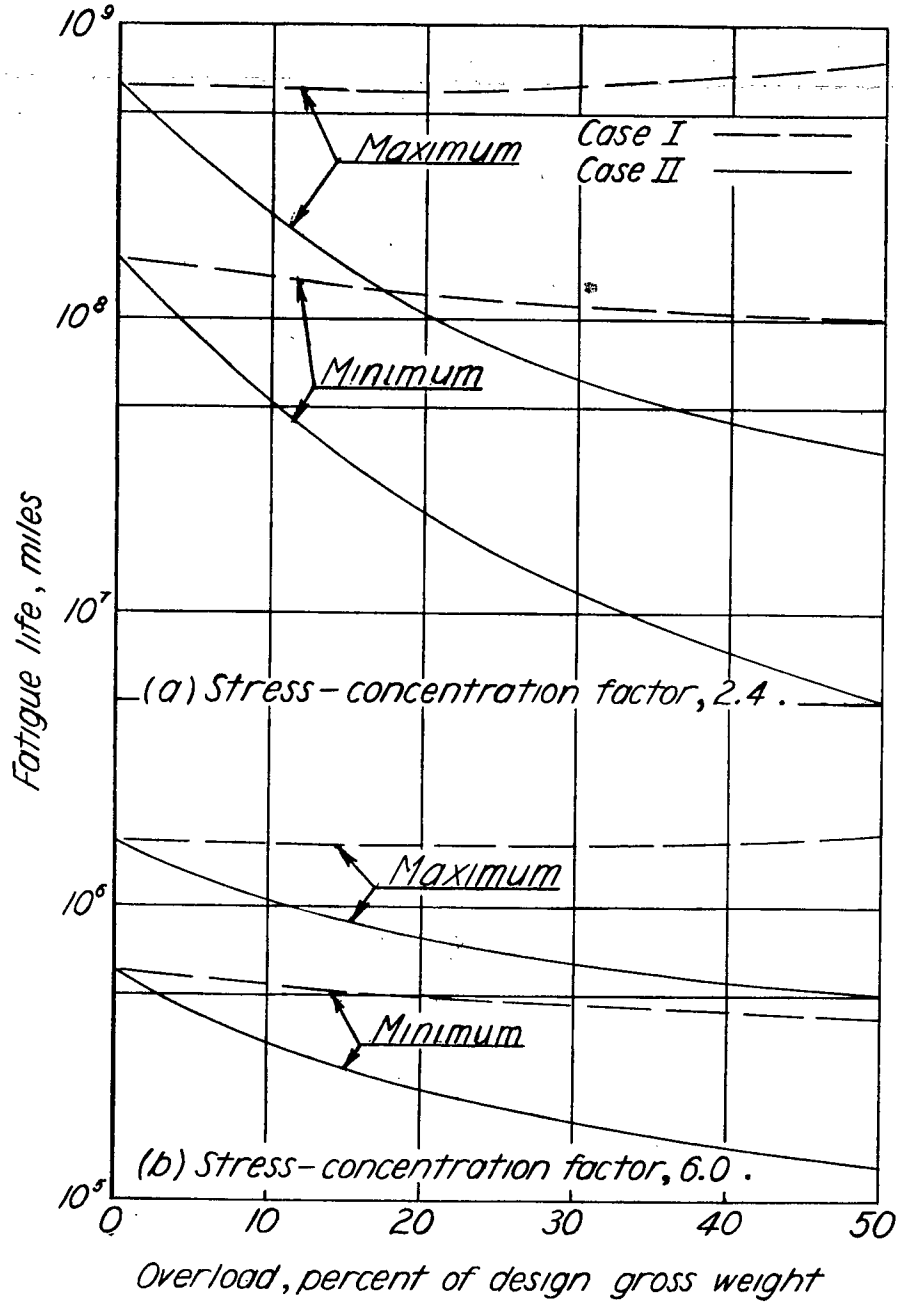


Figure 1.- Variation of maximum and minimum values of fatigue life with overload.

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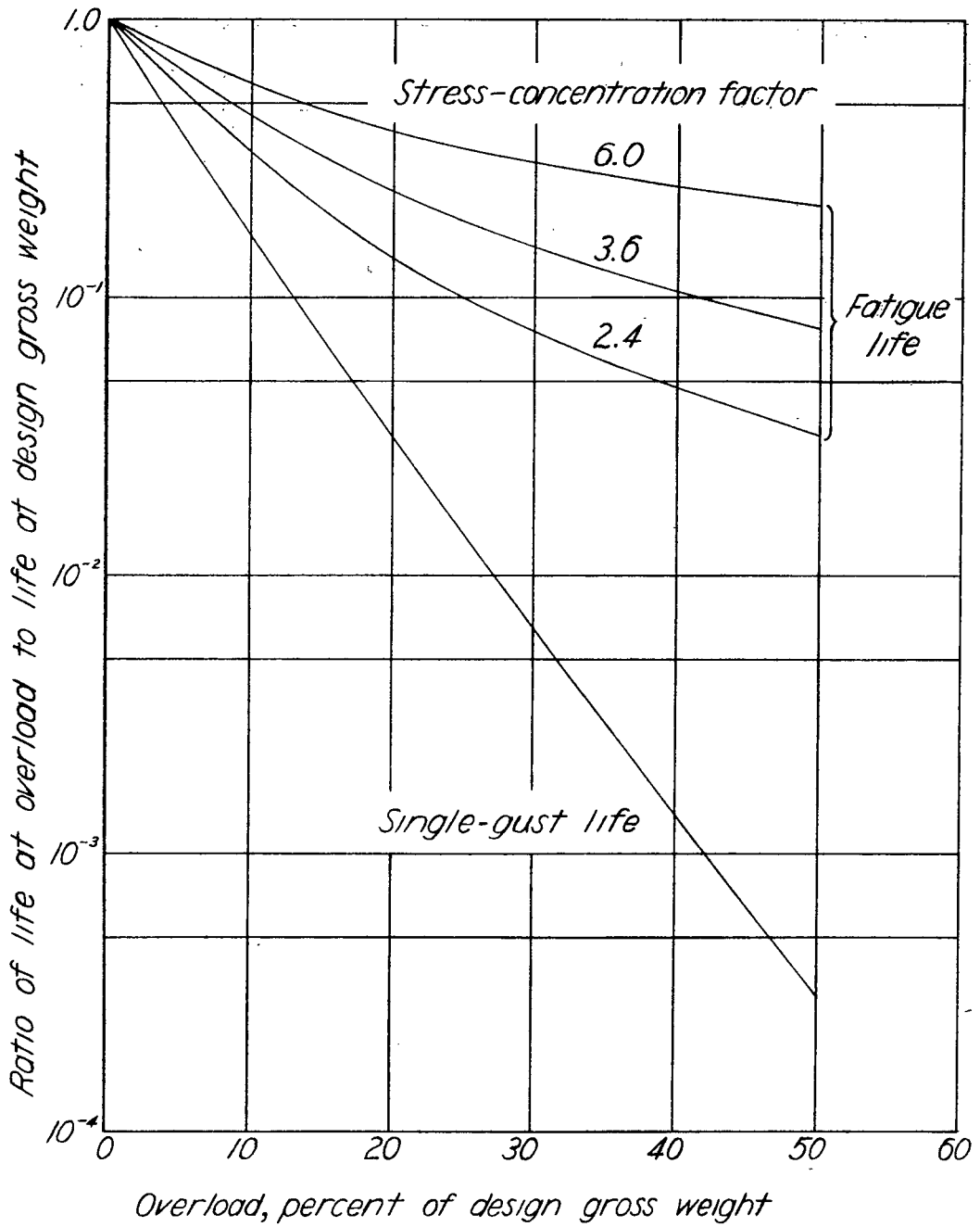


Figure 2.- Effect of concentrated overload (case II) on the ratio of life at overload to life at design gross weight.

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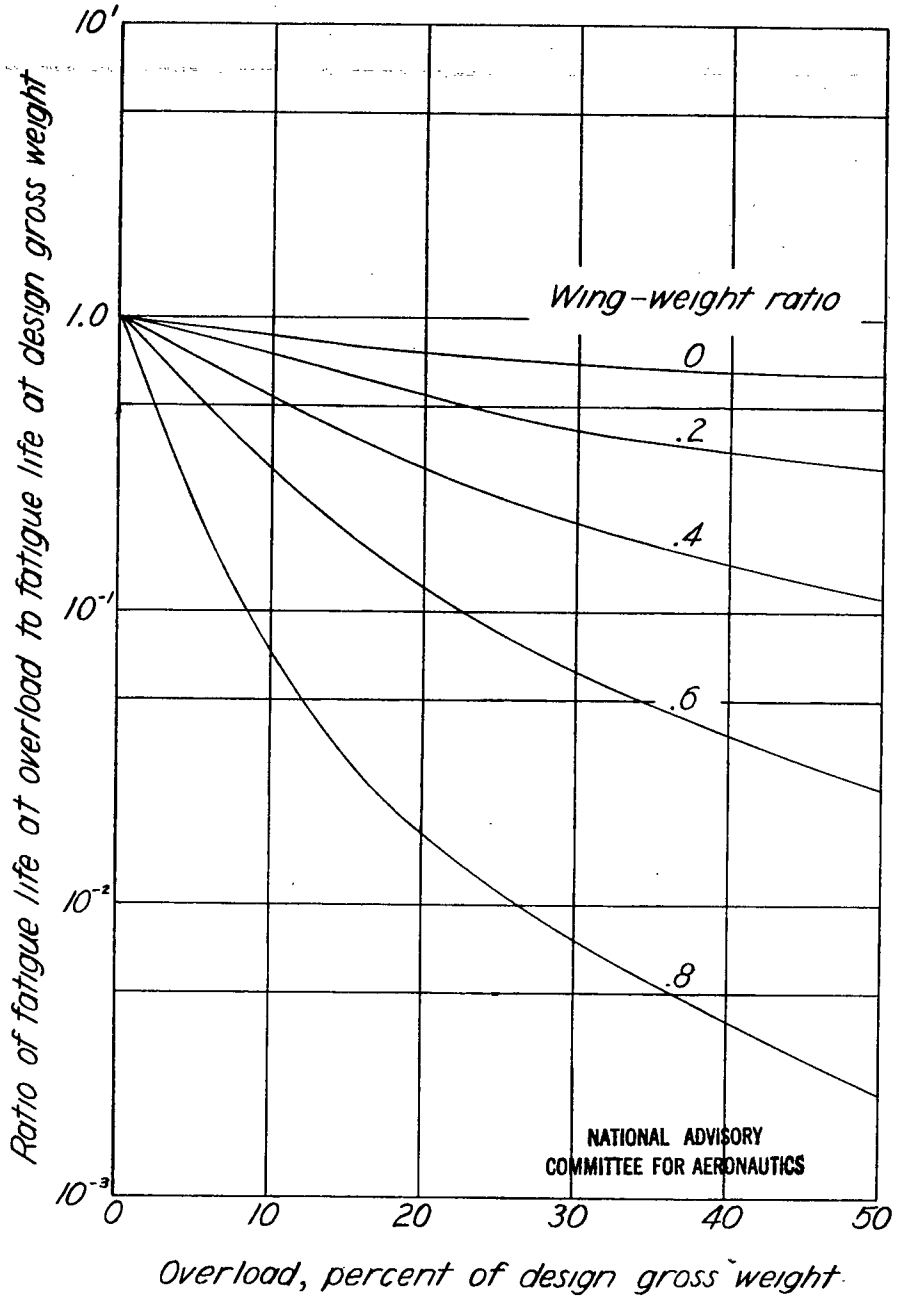


Figure 3.- Effect of wing-weight ratio on the ratio of fatigue life at overload to fatigue life at design gross weight as a function of concentrated overload (case II) for a stress-concentration factor of 2.4.

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